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EXCLUSIVE PHOTOPRODUCTION OF Υ: FROM HERA TO TEVATRON

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The amplitude for photoproduction $\gamma p \to \Upsilon p$ is calculated in a pQCD $k_\perp$-factorization approach. The total cross section for diffractive Υs is compared to recent HERA data. The amplitude is used to predict the cross section for exclusive $p\bar{p} \to p\Upsilon(1S,2S)\bar{p}$ proces in hadronic reactions at Tevatron energies. We also included absorption effects.

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1. Introduction

Exclusive production of heavy $Q\bar{Q}$ vector quarkonium states in hadronic interactions was never measured, but is very attractive from the theoretical side. Due to the negative charge-parity of the vector meson, the Pomeron-Pomeron fusion mechanism of exclusive meson production is not available, and instead the production will proceed via photon–Pomeron fusion. A possible purely hadronic mechanism would involve the elusive Odderon exchange. Currently there is no compelling evidence for the Odderon, and here we restrict ourselves to the photon-Pomeron fusion mechanism. The current experimental analyses at the Tevatron (see, for example, the plenary talk [1]) call for an evaluation of differential distributions including the effects of absorptive corrections. Predictions for Tevatron require the diffractive amplitude for $\gamma p \to \Upsilon p$. This process has been measured at HERA in the energy range $W \sim$ 100 - 200 GeV [2]. This energy range is in fact very much relevant to the exclusive production at Tevatron energies for not too large rapidities of the meson.

2. Photoproduction $\gamma p \to \Upsilon p$ at HERA

The full amplitude for $\gamma p \to \Upsilon p$ process can be written as (it is explained in ref. [3])

$$\mathcal{M}(W,\Delta^2) = (i+\rho)\,\Im m\mathcal{M}(W,\Delta^2=0)\,\exp(-B(W)\Delta^2/2)\,, \tag{1}$$

where ρ is a ratio of real and imaginary part of the amplitude. Imaginary part of the amplitude depends on the light–cone wave function of Υ and the proton's

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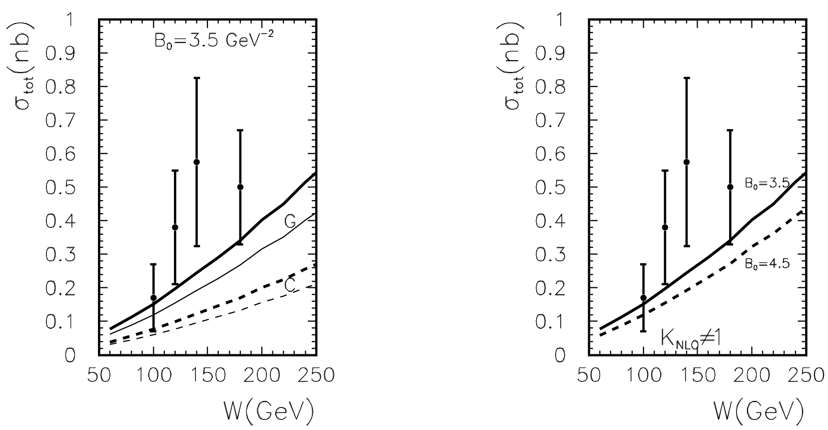

Fig. 1. Total cross section for the $\gamma p \to \Upsilon(1S)p$ as a function of energy. The experimental data are taken from paper [2]. **Left panel**: solid curves - Gaussian (G) wave function, dashed curves - Coulomb (C) wave function. Thick lines were obtained including the NLO correction for the Υ decay width, thin lines are for $K_{NLO} = 1$. **Right panel**: solid curves - $B_0 = 3.5\ GeV^{-2}$, dashed curves - $B_0 = 4.5\ GeV^{-2}$.

unintegrated gluon distribution (taken from Ivanov-Nikolaev) [4,3]. $B(W)$ is slope parameter which depend on energy : $B(W) = B_0 + 2\alpha'_{eff} \log\left(\frac{W^2}{W_0^2}\right)$, with $\alpha'_{eff} = 0.164\ \ \mathrm{GeV}^{-2}$, $W_0 = 95$ GeV (see ref. [5]). Our amplitude is normalized to the total cross section:

$$\sigma_{tot}(\gamma p \to \Upsilon p) = \frac{1+\rho^2}{16\pi B(W)} \left| \Im m \frac{\mathcal{M}(W,0)}{W^2} \right|^2 . \tag{2}$$

In our calculations we used two types of models for the wave functions: a Gaussian and a Coulomb–type one, with a power–law tail in momentum space (ref. [3,4]). Their parameters were fitted to the experimental decay widthes $\Upsilon \to e^+e^-$. The relevant formalism can be found in refs. [4,3]. It involves the NLO–correction factor K_{NLO}. We have calculated for two different choices of factors K_{NLO}. In leading order $K_{NLO} = 1$, and next to leading order approximation $K_{NLO} = 1 - \frac{16}{3\pi}\alpha_S(m_b^2)$.

In Fig. 1 we show the total cross section for the exclusive photoproduction $\gamma p \to \Upsilon p$ as a function of the $\gamma - p$ center-of-mass energy W. In the left panel we show results for the two different wave functions: Gaussian (solid lines) and Coulomb (dashed lines), without (thin lines) and with QCD corrections for the decay width (thick lines). For J/Ψ photoproduction B_0 is $\sim 4.6\ \mathrm{GeV}^{-2}$ (see ref. [6]). It B_0 should be somewhat smaller for the Υ meson. We show the sensitivity to the slope parameter B_0 in the right panel of Fig. 1. Our predictions are systematically somewhat below the experimental data. The results shown in the right panel of Fig. 1 were obtained for the Gaussian wave function and include QCD corrections for the decay width.

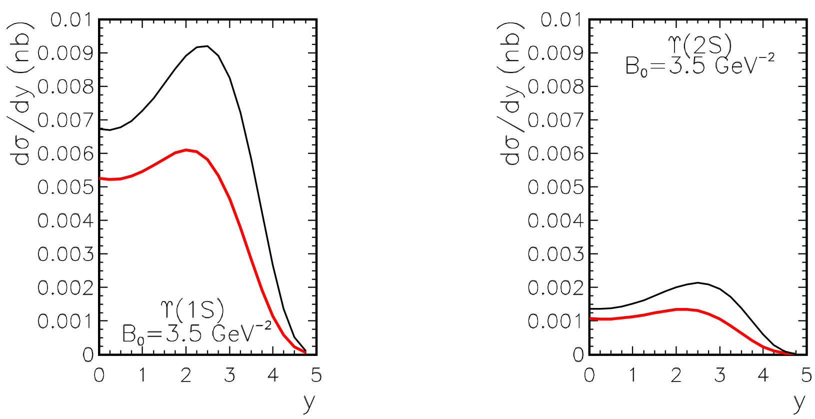

Fig. 2. Differential cross section $d\sigma/dy$ for the Tevatron energy $W = 1960$ GeV. **Left panel**: results for $\Upsilon(1S)$. **Right panel**: results for $\Upsilon(2S)$. The thin solid line is for the calculation with bare amplitude, the thick line for the calculation with absorption effects included.

3. Exclusive photoproduction in $p\bar{p}$ collisions

The full amplitude for $p\bar{p} \longrightarrow p\bar{p}\ \Upsilon$ can be written as

$$\vec{M}(\vec{p_1},\vec{p_2}) = \int \frac{d^2\vec{k}}{(2\pi)^2} S_{el}(\vec{k}) \vec{M}^{(0)}(\vec{p_1}-\vec{k},\vec{p_2}+\vec{k}) = \vec{M}^{(0)}(\vec{p_1},\vec{p_2}) - \delta\vec{M}(\vec{p_1},\vec{p_2}), \quad (3)$$

where

$$S_{el}(\vec{k}) = (2\pi)^2\delta^{(2)}(\vec{k}) - \frac{1}{2}T(\vec{k}),\ T(\vec{k}) = \sigma_{tot}^{p\bar{p}}(s)\exp(-\frac{1}{2}B_{el}\vec{k}^2), \quad (4)$$

with $B_{el} = 17\ \mathrm{GeV}^{-2}$, $\sigma_{tot}^{pp}(s) = 76$ mb (see ref. [3]). Here $\vec{p_1}$ and $\vec{p_2}$ are the transverse momenta of outgoing proton and antiproton.

In formula (3) $\vec{M}^{(0)}(\vec{p_1},\vec{p_2})$ is the Born-amplitude (without absorptive corections) for the process $p\bar{p} \to p\Upsilon\bar{p}$ which includes our amplitude for HERA photoproduction and $\delta\vec{M}(\vec{p_1},\vec{p_2})$ is the absorptive correction. Notice, that both proton and antiproton can emit the photon, and these two contributions interfere in the differential cross section. In particular, the interference is responsible for a dependence on the azimuthal angle ϕ between $\vec{p_1}$ and $\vec{p_2}$.

The differential cross section is given in terms of $\vec{M}$ as

$$d\sigma = \frac{1}{512\pi^4 s^2}|\vec{M}|^2\ dy dt_1 dt_2 d\phi, \quad (5)$$

where y is the rapidity of the vector meson, $t_{1,2} \simeq -\vec{p}_{1,2}^{\,2}$.

The parameters chosen for this calculation correspond to the Gaussian wave function with K_{NLO} included the QCD corrections. In Fig. 2 we show the distribution in rapidity of $\Upsilon(1S)$ (left panel) and $\Upsilon(2S)$ (right panel). Here the absorption effects cause about 20-30% decrease of the cross section.

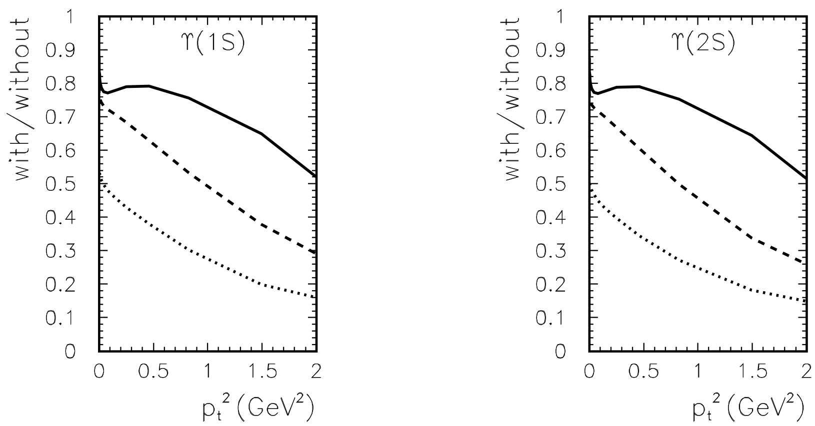

Fig. 3. Ratio of $d\sigma/dydp_t^2$ with absorptive corrections included/ switched off. **Left panel**: Absorption effect for $\Upsilon(1S)$. **Right panel**: the same for $\Upsilon(2S)$. The solid line: $y = 0$, dashed line: $y = 2$, dotted line: $y = 4$.

In Fig. 3 we show the ratio of the invariant cross section with to without absorptive corrections as a function of the Υ–transverse momentum p_t. These results are for different values of rapidity: $y = 0$ (solid lines), $y = 2$ (dashed lines) and $y = 4$ (dotted lines). We can see that absorption effects is bigger for bigger rapidity and also for bigger p_t.

4. Conclusions

The results for $\gamma p \to \Upsilon(1S, 2S)p$ production depend on the model of the wave function. We have compared our results with a recent HERA data. Our results are somewhat lower than the experimental data. The amplitudes for the $\gamma p \to \Upsilon p$ process are used next to calculate the amplitude for the $p\bar{p} \to p\bar{p}\Upsilon$ reaction assuming the photon-Pomeron (Pomeron-photon) underlying dynamics. Absorptive corrections have been included, and they affect the shapes of various distributions. The resulting cross sections are of measurable size.

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